Forces to be overcome in correction of pectus excavatum

Peter G. Weber, MD, Hans P. Huemmer, MD, and Bertram Reingruber, MD

Drs Weber, Huemmer, and Reingruber (*left to right*).

Objective: The Erlangen technique of funnel chest correction is carried out through an anterior incision, and an essential step is retrosternal mobilization. After elevation of the funnel, the chest wall is stabilized with a lightweight transsternal metal implant. Forces necessary to elevate the chest wall were measured at defined intervals during the operation to prospectively assess the effect of peristernal and retrosternal dissection.

Methods: Over a 3-year period, systematic tension measurements were carried out on 100 consecutive patients with symmetric funnel chest to assess the effect of individual steps in mobilization of the sternum.

Results: Whereas in adolescents the extraction force is about 175 N, in adults it is not possible to elevate the sternum to the desired level without surgical mobilization because the force required is, on average, more than 200 N. Only about 50% of this tension can be eliminated by costal chondrotomy. To reduce the tension further and achieve a stable result without the need for heavy-duty internal fixation, we carry out a retrosternal dissection, including removal of the slips of the diaphragm and the insertions of the transversus thoracis muscle. The mean tension at the end of the procedure is 25 N.

Conclusions: Our measurements show that retrosternal dissection is the decisive step in the Erlangen technique, which might explain the low relapse rate and allow for a less extensive anterolateral mobilization.

GTS

The current Erlangen pectus repair method of Huemmer and colleagues[1] is a development of the techniques of Hegemann[2] and Sulamaa and Wallgren[3] and is less invasive. The principle is that the indrawn part of the sternum is mobilized and stabilized with a metal implant under as little tension as possible. Among other techniques,[4-6] our method is most closely related to the method of Fonkalsrud and associates,[6,7] except for details on skin incision, chondrotomy site, and metal bar placement.

Since 1956, more than 3000 chest wall corrections have been carried out in our department. The relapse rate in long-term follow-up is between 2% and 3%.[8]

With systematic analysis of inward forces of the funnel, it has been possible to make the Erlangen technique substantially less invasive: in particular, lateral chondrotomies (ie, division of the ribs at the outer rim of the funnel), previously always carried out, are no longer needed. Extensive rib resections are unnecessary. We also minimize the length of the incision in our technique: whereas 25- to 30-cm incisions were not unusual previously, incisions today are commonly 5 to 8 cm in children and adolescents and 10 cm on average in adults.

This study was undertaken to assess prospectively and objectively the individual effects of peristernal and retrosternal dissection. Forces necessary to elevate the chest wall were measured at defined intervals during the operation.

Materials and Methods

Technique

The lower part of the sternum is freed through a relatively small anterior incision, median in male subjects and submammary in female subjects. Mobilization of the sternum begins with freeing of the xiphoid process.

From the Department of Pediatric Surgery, University of Erlangen, Erlangen, Germany.

Presented at the 14th Annual Meeting of the German Society of Thoracic Surgery [Jahrestagung der Deutschen Gesellschaft für Thoraxchirurgie], Berlin, Germany, June 2-4, 2005.

Received for publication April 13, 2006; revisions received July 17, 2006; accepted for publication Aug 7, 2006.

Address for reprints: Bertram Reingruber, MD, University Department of Pediatric Surgery, Krankenhausstr 12, 91054 Erlangen, Germany (E-mail: bertram.reingruber@gmx.de).

J Thorac Cardiovasc Surg 2006;132:1369-73

0022-5223/$32.00

doi:10.1016/j.jtcvs.2006.08.023

To be able to assess the steps of the Erlangen technique individually, we have for several years made routine measurements of the forces during surgical intervention. We have used as a tensiometer a spring balance with a measurement range of 20 to 230 N (Figure 1). This is attached to the sternum with a hook, and then the sternum is raised to the desired position by pulling on the handle (Figure 2).

When the sternum is mobilized and the forces appear to be low, as in children, the lower costal cartilages are only incised anteriorly at first. The tension measurement determines whether complete division is necessary. The division of the fourth or fifth to seventh costal cartilages eases the retrosternal dissection and is almost a routine step for adults.

If the sternum is very rigidly depressed and also has a pronounced curvature, an osteotomy of its ventral cortex is performed near the apex of the curve.

After these steps, the required force is usually only halved. The sternum becomes more mobile only after retrosternal dissection (ie, division of the sternal part of the diaphragm and the transversus thoracis muscle from the posterior wall of the sternum; Figures 3-6).

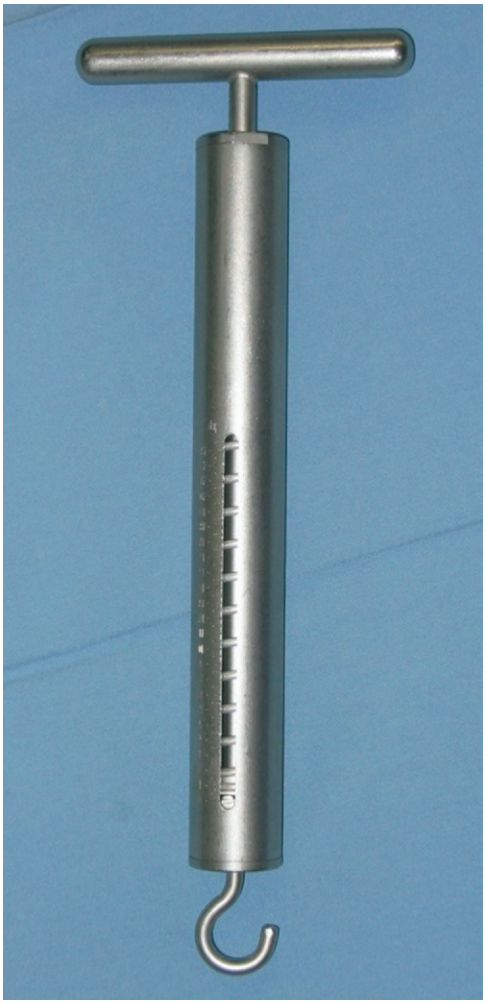

Figure 1. Tensiometer (measurement range, 20-230 N).

Figure 2. Intraoperative tensiometry.

After successful mobilization of the sternum, the Erlangen metal plate is placed transsternally. This is made of steel (or titanium if the patient is allergic) and measures 8 × 2 mm in cross-section, and its length can be tailored to fit each patient. This

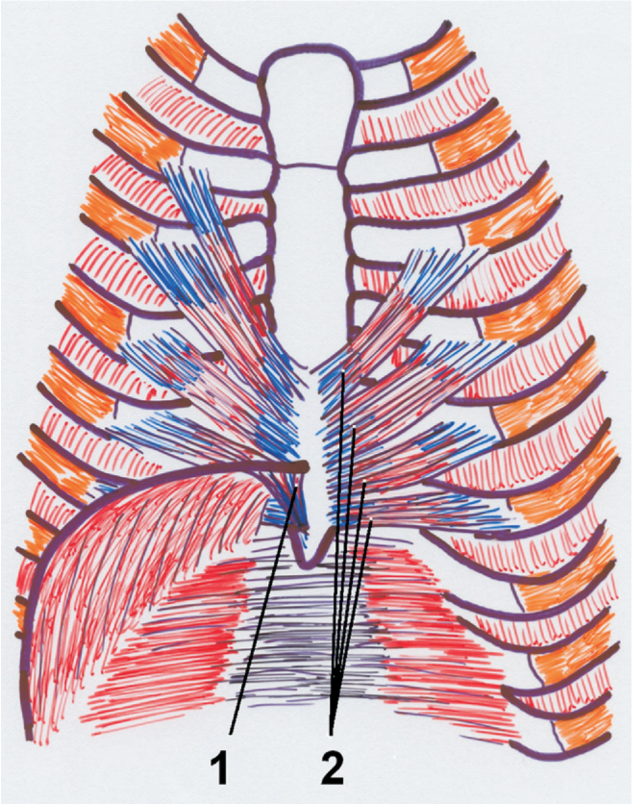

Figure 3. Internal view of the anterior chest wall (schematic). *1,* Sternal part of the diaphragm; *2,* sternal part of the transversus thoracis muscle.

GTS

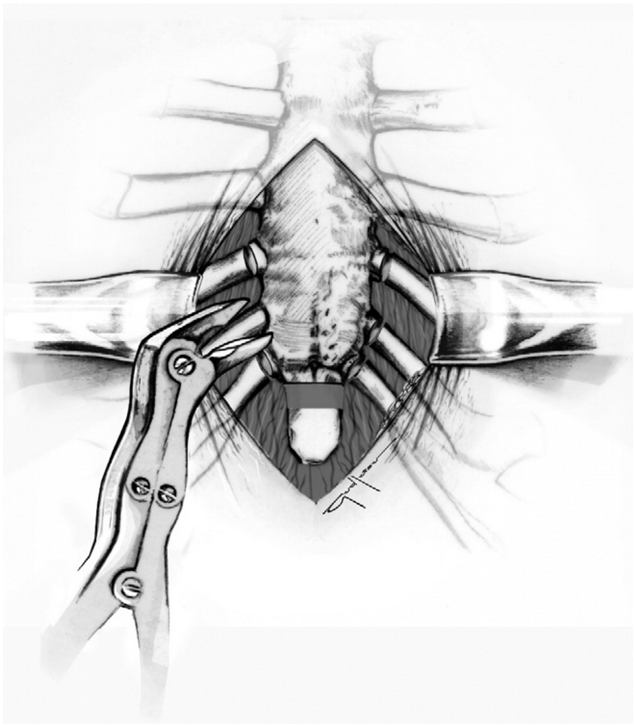

Figure 4. Taking out thin chips of costal cartilage medially and parasternally.

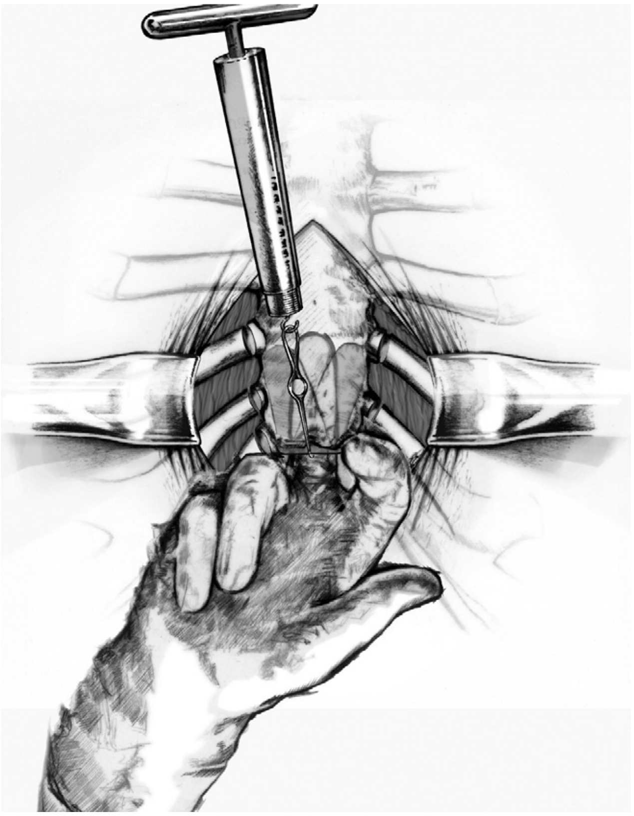

Figure 5. Blunt dissection of the retrosternal attachments.

implant is relatively lightweight: a 19-cm plate, for example, weighs 21 g.

The divided costal cartilages are individually refashioned, and the congruent sections are reattached with strong absorbable sutures. Occasionally these costal cartilages are shortened to achieve congruence. After placing wound drains, the chest wall is closed. The patient is transferred to a regular ward immediately and is discharged from the hospital after 6 to 10 days. We routinely remove the metal plate after 1 year through a lateral stab incision.

Patients and Methods

Intraoperative tension measurements in 100 funnel chest correction operations from 2001 through 2004 were retrospectively analyzed. These involved 89 male patients (89%) aged 5 to 48 years and 11 female patients (11%) aged 10 to 33 years.

The patients were grouped by age and sex. Adolescent and adult patients were grouped together.

The average operation time was 82 minutes (range, 41-119 minutes) for male children (n = 31), 101 minutes (range, 58-142 minutes) for male adults (n = 58), 93 minutes (range, 65-125 minutes) for female children (n = 6), and 116 minutes (range, 78-160 minutes) for female adults (n = 4). One female adult was not included in the analysis of operative time because she had bilateral renewal of breast implants at the same visit (total operation time, 176 minutes).

Measurements

During the Erlangen funnel chest correction procedure, a tensiometer with a measurement range of 20 to 230 N was used. This was attached to the tip of the sternum with a single-pronged hook. The sternum was then elevated to the desired level by pulling on the handle, and the required force was recorded. For older male patients, where the force commonly exceeded the maximum 230 N registered on the tensiometer, a figure of 250 N was used in the analysis.

Analysis

The force measurements at each of the 4 essential steps in mobilization were analyzed (Table 1): before mobilization (ie, after division of the xiphoid process; F1), after medial chondrotomy of the lower costal cartilages (F2), after osteotomy of the anterior cortex of the sternum if carried out (F3), and after the retrosternal dissection (F4).

Results

The decisive step of tension reduction is between F2 (or F3 if sternal osteotomy is carried out) and F4. These differences were highly significant ($P < .0001$).

Complications and Outcome

There was complete follow-up of all 100 patients undergoing surgical intervention for funnel chest between 2001 and

Table 1. Analysis of the first 100 patients with funnel chest who underwent tensiometry

	F1	F2	F3	F4
Male (5-17 y)				
Mean	181 N	98 N	67 N	29 N
SD	48.3 N	42.8 N	31.3 N	17.5 N
Median	195 N	80 N	60 N	30 N
Range	80-250 N	40-190 N	45-150 N	5-50 N
N	31	31	11	29
Male (18-48 y)				
Mean	231 N	137 N	89 N	27 N
SD	30.5 N	31.4 N	30.2 N	15.0 N
Median	250 N	140 N	90 N	25 N
Range	170-250 N	60-185 N	40-130 N	5-70 N
N	58	58	25	51
Female (10-17 y)				
Mean	153 N	97 N	115 N	18 N
SD	55.6 N	42.2 N	5.0 N	7.5 N
Median	170 N	115 N	115 N	15 N
Range	70-220 N	35-150 N	110-120 N	10-30 N
N	6	6	2	5
Female (18-34 y)				
Mean	200 N	123 N	70 N	32 N
SD	7.1 N	17.4 N	0.0 N	1.8 N
Median	200 N	130 N	70 N	30 N
Range	190-210 N	100-140 N	—	30-35 N
N	5	5	1	4

F1, Measurements after division of the xiphoid process; *F2*, measurements after medial chondrotomy; *F3*, measurements after osteotomy of the ventral cortex of the sternum (not performed routinely); *F4*, measurements after retrosternal dissection (ie, division of the slips of the diaphragm and transversus thoracis muscle).

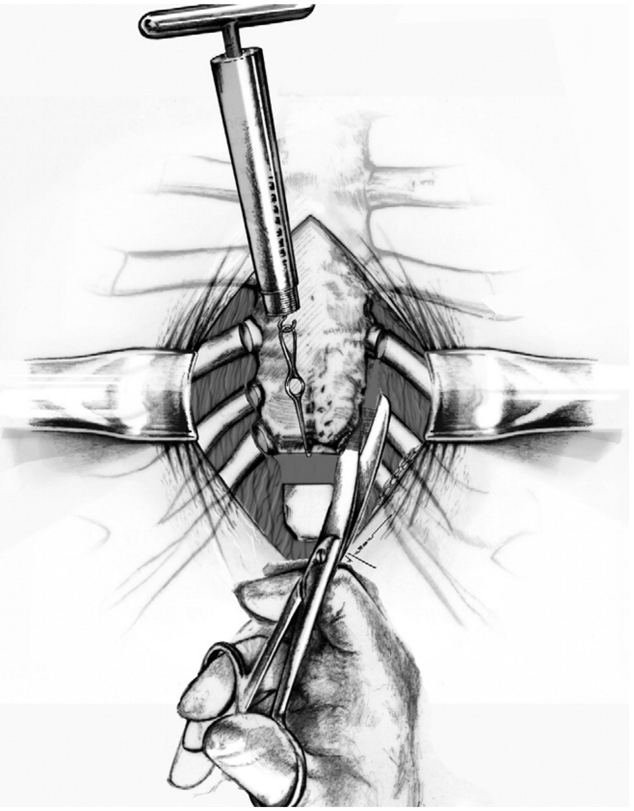

Figure 6. Division of the slips of the diaphragm and transversus thoracis muscle.

GTS

2004, with a follow-up period of between 1 and 4 years and a minimum of 12 months. There were no deaths; minor complications included 1 wound infection, 2 pleural effusions requiring drainage, 6 wound seromas, 2 sternal dislocations of the metal bar, and 1 case of persistent pain requiring lateral shortening of the bar.

The bar is removed 1 year later through a small lateral stab incision. Minor corrections can be performed on this occasion. In the present series we removed minor parasternal cartilaginous protrusions in 4 cases and excised 12 hypertrophic scars. The funnel relapse rate in the present series was 2%. All other patients described the results as good or excellent.

Discussion

The cause of funnel chest is not entirely clear. The retraction theory, already developed in the 16th century by Bauhin[9] (1541-1613), attributes the deformity to the backward pull of the diaphragm. In probably the earliest description of a funnel chest, in a letter to a friend from the year 1594, he writes, "My father showed me a seven-year-old boy, . . . whose breastbone and costal cartilages were bowed so far inwards that a great hollow was formed. The diaphragm seemed to bring these parts even further together."

In 1939, Brown[10] described the division of the xiphoid process, the removal of the slips of the diaphragm from the breastbone, and the division of the "ligamentum substernale" and recommended this treatment for small children. Such a ligament does not, however, exist anatomically.

Retrosternal dissection was routinely carried out in the Erlangen method before the introduction of tensiometry, although we had not quantified its effects. Our measurements show that the slips of the diaphragm and the transversus thoracis muscle exert substantial tension on the inferior part of the sternum. Systematic measurements show that some common earlier operative steps, in particular the resection of costal cartilages and sternotomy for mobilization, are in most cases unnecessary.

We have shown that careful retrosternal dissection is the key step in the correction of funnel chest, and it might account for our good long-term outcomes. By concentrating the operative efforts on these essential steps of mobilization, the extent of the dissection can be reduced, and patient comfort and cosmesis can be improved without risking an increase in the relapse rate.

Conversely, in other surgical methods in which retrosternal attachments are left in place, their tensile forces might cause relapse once the metal implants have been removed.

References

1. Huemmer HP, Reingruber B, Weber PG, Schreiber M. Minimizing a conventional operation technique; the Erlangen method of funnel chest repair. Presented at the 121st meeting of the German Society of Surgeons (121, Kongress der Deutsuhen Gesellschaft für Chirurgie), Berlin, May 2004.
2. Hegemann G. Kosmetische und funktionelle Ergebnisse operativer Maβnahmen bei Trichterbrust. *Langenbecks Arch Klin Chir.* 1967; 319:526.
3. Sulamaa M, Wallgren E. Trichterbrust. *Z Kinderchir.* 1970;8:22.
4. Ravitch MM. The operative treatment of pectus excavatum. *Ann Surg.* 1949;129:429-44.
5. Nuss D. A 10-year review of a minimally invasive technique for the correction of pectus excavatum. *J Pediatr Surg.* 1998;4: 545-52.
6. Fonkalsrud EW, Dunn JCY, Atkinson JB. Repair of pectus excavatum deformities: 30 years of experience with 375 patients. *Ann Surg.* 2000;231:443-8.
7. Fonkalsrud EW, Mendoza J. Open repair of pectus excavatum and carinatum deformities with minimal cartilage resection. *Am J Surg.* 2006;191:779-84.
8. Weber PG, Carbon RT, Huemmer HP, Reingruber B. Fifty years of funnel chest repair in Erlangen. Poster presented at: 100th Annual Conference of the German Society of Pediatrics (Jahrestagung der Deutschen Gesellschaft für Kinderheilkude und Jugendmedizin); Bremen; Sept 30, 2005.
9. Bauhin J. Sterni cum costis ad interna reflexis spirandi difficultatis cause. Frankfurt: Schenk und Frankenberg; 1600.
10. Brown LA. Pectus excavatum (funnel chest). *J Thorac Surg.* 1939;2: 164-84.

GTS